NEXT-LEVEL AGRI-PV: VERTICAL TRIPLE-MODULE STACK FOR FUTURE-READY FARMING

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ABSTRACT:

Vertical bifacial (VB) agrivoltaic (APV) systems represent a promising **dual-use concept** that enables the simultaneous production of food and renewable energy. This study examines the technical, agricultural, and energy-economic performance of Next2Sun's vertical Agri-PV system. Moreover, a particular showcase from the world's first 3-module-stack vertical Agri-Solar Park Löffingen (4.3 MWp, Germany) is provided.

Several agronomic advantages of the VB System are highlighted such as **uniform light and rain distribution**, **reduced wind speeds, and minimized shading**, which result in high land usability and preserved crop cultivation between module rows. First agricultural results from comparable European installations indicate stable or even **enhanced crop yields** for wheat, barley, and millet, provided that soil compaction from construction is mitigated. Microclimatic analyses show typical light availability of around 80% at the Löffingen spacing (13.5 m), wind speed reductions of ~50%, and homogenized rain distribution. These factors collectively decrease evapotranspiration by 5–40%, while increasing water availability for crops - an advantage under rising climate stress.

The east–west oriented bifacial design further **supports a demand-oriented electricity generation profile**, improved grid integration, and less negative market-price hours. Early electrical performance data from 2025 demonstrate that the vertical east–west system already outperforms the conventional south-oriented PV section in **energy yield and revenue per MWh**. The data also indicates that vertical generation profiles are less affected by curtailment due to their broader and more market-aligned output. An optional battery storage further increases revenue potential by shifting energy into high-price periods. Overall, the Löffingen case confirms that VB-APV systems can enable profitable renewable electricity generation while maintaining full agricultural productivity.

Keywords: Agrivoltaics, grid-friendly PV generation, 3-row vertical PV, dual-use land management

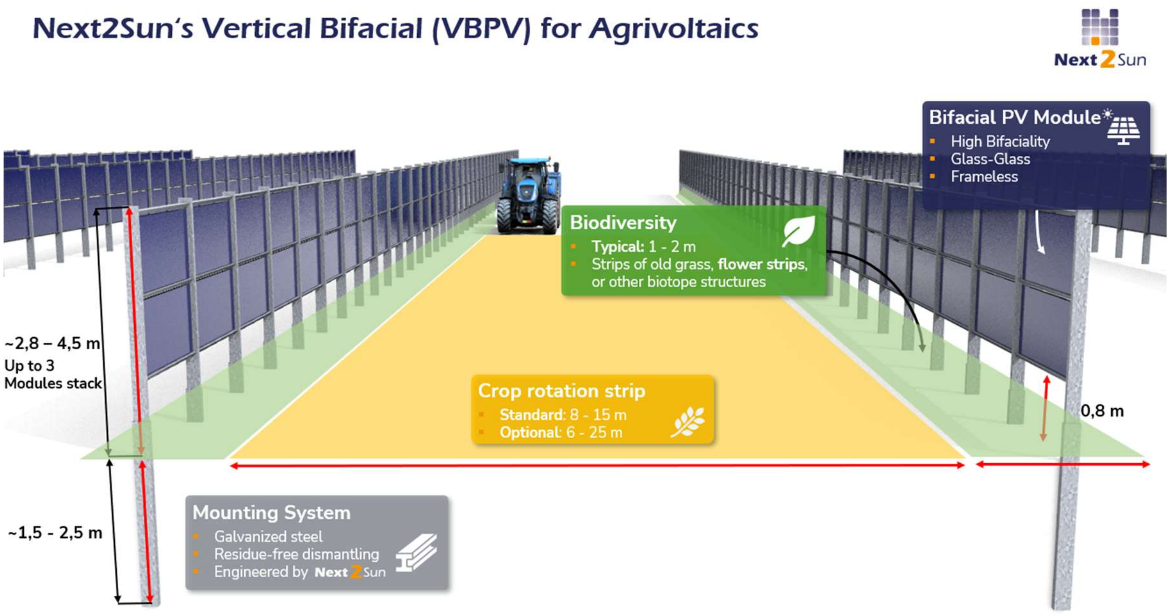

Figure 1: Typical system setup of a vertical PV powerplant designed by Next2Sun

1 INTRODUCTION

Various solutions exist for installing PV modules in agrivoltaics (APV), such as tilted but spaced (fixed or tracked) ground-mounted systems or elevated systems (fixed or tracked). This study focuses on fixed vertical bifacial (VB) systems, as depicted in Figure 3. The multiple benefits of VB systems for agriculture, as described in the literature, include uniform light and rainwater distribution for crops and protection against strong winds from directions perpendicular to the PV module orientation [1]. In addition to these agricultural benefits, the profitability and grid serviceability of vertical bifacial PV systems, discussed in [2], are confirmed in previous work [3, 4, 5, 6].

2 CONCEPTS OF VERTICAL AGRI PV

Traditional agriculture and sophisticated forms of energy generation are not mutually exclusive. Next2Sun's vertical Agri-PV concept, as shown in (**Figure 1**), represents a combined solution with minimal ground coverage (<1%) land-use (<15%) and renewable energy production which is mostly demand-oriented by design. The installation uses a robust racking structure made of high-quality steel with pile-driven posts capable of supporting up to three vertically stacked PV modules, reaching system heights of up to 4.5 m. Next2Sun engineered the racking system and module design together to minimize self-shading losses in the system. Moreover, the vertical arrangement minimizes shading on adjacent agricultural areas as well as soiling on the modules while ensuring structural stability against wind loads. Wide crop rotation strips, typically ranging from 8 to 15 m, ensure full agricultural usability.

From an energy generation perspective, the system employs high-efficiency bifacial PV modules, which are optimally suited to capture diffuse irradiation as well as direct sunlight from both east and west directions. This design leads to a generation profile with a broader distribution of electricity production throughout typical days, better aligning with consumption patterns and enhancing grid integration [3, 7].

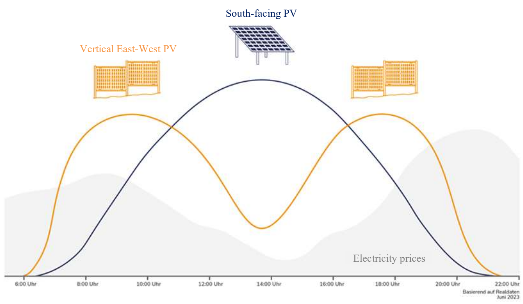

Figure 2: Typical power production profile for clear-sky conditions of a conventional south-facing PV system and the vertical bifacial PV by Next2Sun

Combined with the preserved agricultural productivity, this dual-use approach increases overall land-use efficiency and can contribute to both food and energy security.

Summing up the key points of Next2Sun's vertical AgriPV System:

- **Dual use of land**
- **Agricultural compatibility / low shade impact to crops**
- **Longevity due to robust racking**
- **High specific electrical yield**
- **Demand-oriented electricity production**

3 USE-CASE SP LOEFFINGEN

The Agri-Solar Park in Löffingen, seen in **Figure 3** combines electricity generation with active agriculture on an area of 11 ha. Operation to the grid started in May 2025. Across the site, a total PV power of 4.3 MWp is installed, split into a conventional fixed-tilt south-oriented PV of about 1 MWp and vertically east-west facing 3.3 MWp. Combined an annual output of around 4,800 MWh is fed into the grid. Thereby the vertical system is supported by battery storage of 1288 kWh (and 736 kW), which further increases the profitability by shifting energy into high-price periods.

Figure 3: Vertical bifacial power plant built by Next2Sun in Löffingen (Germany)

To maximize electricity yield despite optimal spacing for the needs of the farmer, it was decided to arrange three modules on top of each other for most of the module rows. Thereby the row-spacing is set to 13.5 m. Next2Sun mastered the associated challenges, in particular the increased wind loads, through its proven technical expertise.

Both arable farming and grassland are practiced between the rows of modules, as part of the site is used for cattle farming. The arable part is used to grow crops such as spelt, oats and buckwheat.

Table 1: Technical Details of SP Löffingen

Annual Energy	Approx. 4800 MWh / a
Installed power	4.3 MWp (3.3MWp VB + ~1MWp FT South)
Azimuth	Mostly vertical East-West (90°/-90°)
Row distance	13.5 m
Agricultural use	Arable farming, grassland, pasture farming
Electricity usage	Grid feed-in according to EEG + integrated battery storage in INNO

4 MEASUREMENTS / RESULTS

Aside from the ramp-up of the power production in May 2025, the agricultural stewardship started at the end of 2024. Therefore, major parts of the land were used for mustard cultivation, which was successfully harvested in August 2025. A picture of the harvesting in between the rows is shown in Figure 4.

Figure 4: First harvesting of mustard at the plant in August 2025

4-1 Agricultural / Environmental Aspects

Researchers from the LAZBW (Agricultural Center Baden-Württemberg) are currently conducting surveys on grassland growth, biodiversity, and microclimate on the site in Löffingen as part of the "Model Region Baden-Württemberg" project led by Fraunhofer ISE. Unfortunately, as the project is still in its early stages, no evaluations of the measurements and surveys on the site are available yet. Therefore, in the following section, we will attempt to describe the results we expect for the Löffingen site based on previous results and experiences.

Crop yields

Regarding crop yields, we can draw on cultivation results for three different crops that are suitable for the location and planned crop rotation: wheat, barley, and millet (**Figure** 5). The results all originate from European Next2Sun installations (except for one shading net trial) and were collected and published by independent research institutions. The crop yields of winter wheat and winter barley (except for the results affected by soil compaction) as well as moha millet were lower at the various locations in different years, with average plant yields[1] of 111% (wheat), 100% (barley)[2] and 132% (millet) appear very promising. Consequently, on average, a maintenance or increase in crop yield can be expected. However, it should be noted that various factors may limit this. Studies show that the first yield after construction of the plant can be negatively affected by soil compaction due to the construction process [8], [9]Accordingly, a soil-conserving construction process and suitable after-treatment of the soil (e.g., deep loosening and soil-loosening follow-up crops) are crucial for rapid soil regeneration. Another limiting factor with regard to the yield data is that these are annual results per location. Evaluations from subsequent years are therefore important to be able to derive a more representative yield picture in the future, especially depending on the weather conditions of the year.

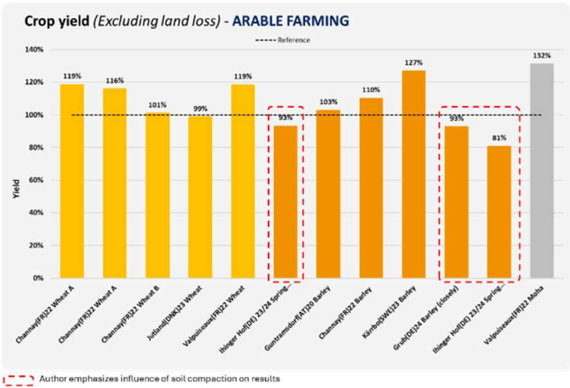

Figure 5: Crop yields of Wheat (yellow), Barley (orange) and millet (grey) within Next2Sun facilities; Results marked in red are negatively affected by soil compaction, according to the authors and therefore less representative

Crop quality

In addition to yield quantity, yield quality plays an equally important role. This determines marketability and, consequently, the value of the crop.

With regard to **protein content**, empirical values are available for wheat and barley. Various wheat varieties in France showed no significant deviations in protein content compared to the unshaded reference [10]. According to current knowledge, protein contents of barley behave somewhat differently. A study from Sweden showed slight, but not significant, reductions in protein content, whereas two studies from France and southern Germany found protein levels to have increased by around 8% [9] [10] [11] . Despite the sometimes-significant increases, all three protein levels in barley between the vertical rows of modules still showed optimal range protein content of between 12-14% [12].

Further empirical values based on scientifically evaluated field data are available with regard to **harvest moisture**. Both in cultivation trials in France (wheat, barley, and millet) as well as in Austria Contrary to expectations, comparable to minimally lower harvest moisture levels were consistently detected (soybeans) [10] [13]. Due, in particular, to lower solar radiation and lower convective moisture removal as a result of lower wind speeds within the system, it was previously assumed that there could be challenges with increased harvest moisture levels in connection with vertical bifacial APV systems. The

[1]Excluding land losses of typically 10-15%

[2]Accounting the negative impact of soil compaction

studies conducted to date refute this assumption at this point in time.

Microclimate
The microclimate within the facility, together with the soil conditions, determines the growth potential of the crops to be cultivated. Next2Sun has developed a very solid understanding of the microclimatic conditions prevailing within vertical APV facilities with the help of its own measurements, specially developed simulation tools, and cooperation with research partners.

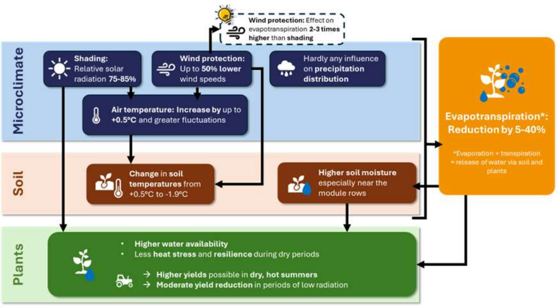

Figure 6: Overview of microclimatic effects in vertical bifacial APV systems

Starting with what is probably the most popular scientific parameter, **light availability**: with the help of measurements supplemented by ray tracing simulation tools, the light available to plants (PAR) can be predicted with astonishing accuracy. Consequently, in Central Europe, with typical row spacings of 9-15 m, light availability is 75-85% and shading is 15-25%. In the specific case of Löffingen, the extended row spacing of 13.5 m means that, despite the high module rows (3 modules on top of each other), light availability of approx. 80% can be expected.

Wind
Another characteristic feature of vertical APV systems is their ability to block the wind, particularly in module orientations that are perpendicular to the main wind direction at the site. Previous measurements and results show an impressive consensus that wind speeds between the rows are reduced by an average of 50% compared to undeveloped agricultural land. With regard to the plant in Löffingen, even higher average wind reductions can be expected due to the higher module rows at ground or plant level, which will have a positive effect on reduced wind erosion and evapotranspiration (= increased water availability for plants). Another interesting and often underestimated finding is that the reduced wind speed has a 2-3 times greater impact on reduced evapotranspiration than the reduction in solar radiation, which is a unique selling point of vertical APV.

Rain distribution
In addition, vertical mounting enables very homogeneous rain distribution across the surface and prevents water-eroding drip edges. Tests show that rain availability is only 5% lower in the areas close to the modules, which illustrates the homogeneous water distribution.

Evapotranspiration
All of the microclimatic conditions described above interact and contribute to increased water availability for plants, which can be quantified by a lower **evapotranspiration rate**. The latter (lower evapotranspiration rate) is quantified in vertical systems by measurements in combination with simulations in relevant publications depending on the site conditions at 5-40%. The main beneficiaries of this are cultivated crops, which benefit from the increased water availability, particularly during increasingly frequent dry periods with water stress. The relevant accompanying research in Löffingen will show whether the positive effects described here can also be observed in this area.

4-2 Electrical Performance

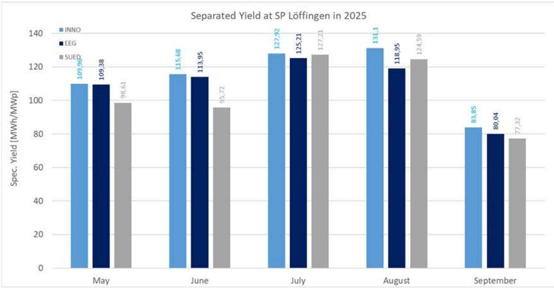

Figure 7: Measurements of specific yield separated in the different trade-zones in SP Löffingen (vertical east-west in light-blue INNO and dark-blue EEG, south-facing fixed-tilt in grey)

Since feed-in began in April 2025, no full year of production is available yet. However, the accessible data (shown in Figure 7) already shows that the vertical east-west facing systems feed more energy into the grid than the conventional south-facing part. Unless the number of negative hours is low, as for example in July and August 2025. Note, all subsystems (Vertical, Vertical + Storage and Conventional) exhibit curtailment during periods of negative spot-market prices. The INNO subpart featuring the battery storage introduces slightly more energy into the grid in all months of 2025 (except for August). Presented Data is measured on 5-minutes resolution at the AC side of the inverters.

4-3 Revenues of electricity trading

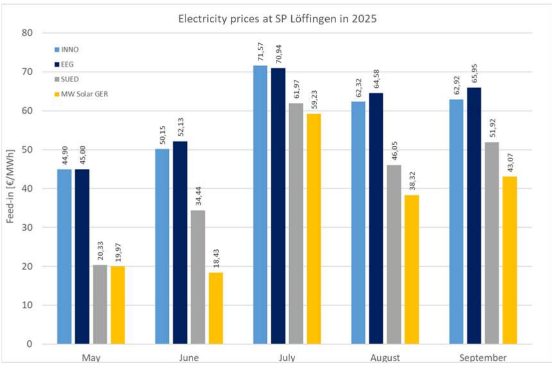

Figure 8: Electricity prices in SP Löffingen for 2025, separated in the trading zones

In addition to the depicted specific yield, it is also worth mentioning the measured electricity prices for the three subsystems (Vertical, Vertical + Storage and Conventional) in Löffingen. While the curtailment activated in June 2025 leads to a reduced amount of energy introduced to the grid, the absolute revenues benefit by the cut-off and lead to significantly higher specific remuneration as presented in Figure **8**. When compared to the average market-value of the PV portfolio Germany ("MW Solar GER"), all 3 subsystems outperformed the portfolio in every month after activation. July 2025 recorded no negative prices and therefore no curtailment, hence the profile values converge. Months with higher number of negative prices impact on all 3 trading zones, but as can be seen in the bar chart the vertical east-west profile is impacted less significant when compared to the south-fixed curtailed and portfolio prices. Note that the extra feed-in of the battery in the INNO part is not yet included in the graph and will further benefit the revenue.

CONCLUSION & OUTLOOK

Vertical bifacial agrivoltaics approaches designed by Next2Sun demonstrate that agriculture and photovoltaics can be synergistically combined without compromising land use or crop productivity. The use-case Löffingen confirms the robustness and agricultural compatibility of the Next2Sun system, while early performance data show clear electrical and economic advantages over conventional PV installations. With stable crop yields, improved microclimatic conditions, high land-use efficiency, and strong market-aligned energy generation, vertical Agri-PV stands out as a scalable dual-use solution It can contribute simultaneously to food and energy security, climate adaptation, and the further expansion of renewable energy.

In addition to the accompanying research currently being conducted at the Löffingen solar park, additional research in the field of microclimate research will be carried out in the next years. The Löffingen solar park is particularly suitable for this purpose, as it has sections with single-row and triple-row vertical arrays as well as a section with elevated inclined modules with three different module occupancy densities. This experimental design offers a unique comparison of microclimate parameters. A Swedish institute, in cooperation with German researchers, will use this to gain further insights, particularly into rain and water distribution among the various APV concepts.

Research institutions which are interested in data on this specific case should not hesitate to contact us.

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